ECOSYSTEM STATUS INDICATORS
Physical Environment

EASTERN BERING SEA
Temperature and Ice Cover - FOCI
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Last updated: September 2005

***Summary**. The anomalously warm winter of 2005 follows similarly warm winters of 2003 and 2004. Although surface air temperature in the winter of 2002 was colder than 1961-2000 average, the depth-integrated temperatures at Mooring 2 indicate that the shift to warmer conditions in the Bering Sea began in the spring of 2000. This warming becomes comparable in its scale with major warm episodes in the late 1930s and late 1970s – early 1980s. The spring transition is occurring earlier, and the number of days with ice cover after March 15 has a significant downward trend. In 2005, the ice cover index reached the record low value. The lack of ice cover over the southeastern shelf during recent winters resulted in significantly higher heat content in the water column. Sea surface temperature in May 2005 was above its long-term average value, which means that the summer bottom temperatures will likely be also above average.*

The winter of 2005 in the Bering Sea was anomalously warm, with the mean winter (DJFM) surface air temperature (SAT) at St. Paul being 2.34°C (or 1.4 standard deviations) above the 1961-2000 average. This increases our confidence that a shift toward a warmer climate in the Bering Sea occurred in 2001 (Figure 18a). The significance level for this shift is 0.09, which is based on the two-tailed Student t-test for the difference in the mean SAT values for the periods 1990-2000 and 2001-2005. This difference would have been even more statistically significant if there were no “outliers”, specifically, a cold winter in 2002, and a warm winter in 1996. In response to this warming, the Bering Sea is experiencing a northward biogeographical shift (Overland and Stabeno 2004). If this shift continues over the next decade, it will have major impacts on commercial and subsistence harvests as Arctic species are displaced by sub-Arctic species.

Milder winters in the Bering Sea can partly be explained by the tendency for anomalously low SLP (Figure 18b), which indicates an enhanced cyclonic activity and increased advection of warm Pacific air. The level of cyclonic activity over the Bering Sea is linked to the strength of the Aleutian low, but it can also be associated with the north-south dipole of the Victoria pattern. The shift in Bering Sea pressure index (BSPI) in 1977 reflects the basin-wide climate shift and strengthening of the Aleutian low. The 1989 and 1998 shifts in the BSPI appear to be mostly a response to phase shifts in the Victoria pattern. In addition to cyclonic activity, an important factor responsible for thermal conditions in the Bering Sea is the mean meridional flow in the lower troposphere. As discussed in the Pacific section of the report, the East-Central North Pacific (ECNP) index (which takes into account both these factors) showed a statistically significant increase since 2000, suggesting greater Pacific influence on the Bering Sea.

This recent warming in the Bering Sea is not confined to the winter season. Figure 19a shows monthly SAT anomalies at St. Paul for the period from January 1995 through May 2005. Note the sharp transition from very low temperatures in the early winter of 2000 to anomalously warm conditions in late winter and spring of that year. Similar transitions, to a lesser degree, were observed in winter-spring of 1998 and 2002. Stabeno and Overland (2001) argue that the Bering Sea appears to have shifted toward a pattern of earlier spring transition. Since March 2002, SAT anomalies remained positive for 37 consecutive months until April 2005, which was slightly colder than normal. This is the longest run of positive SAT anomalies during the period of record extending back to 1916.

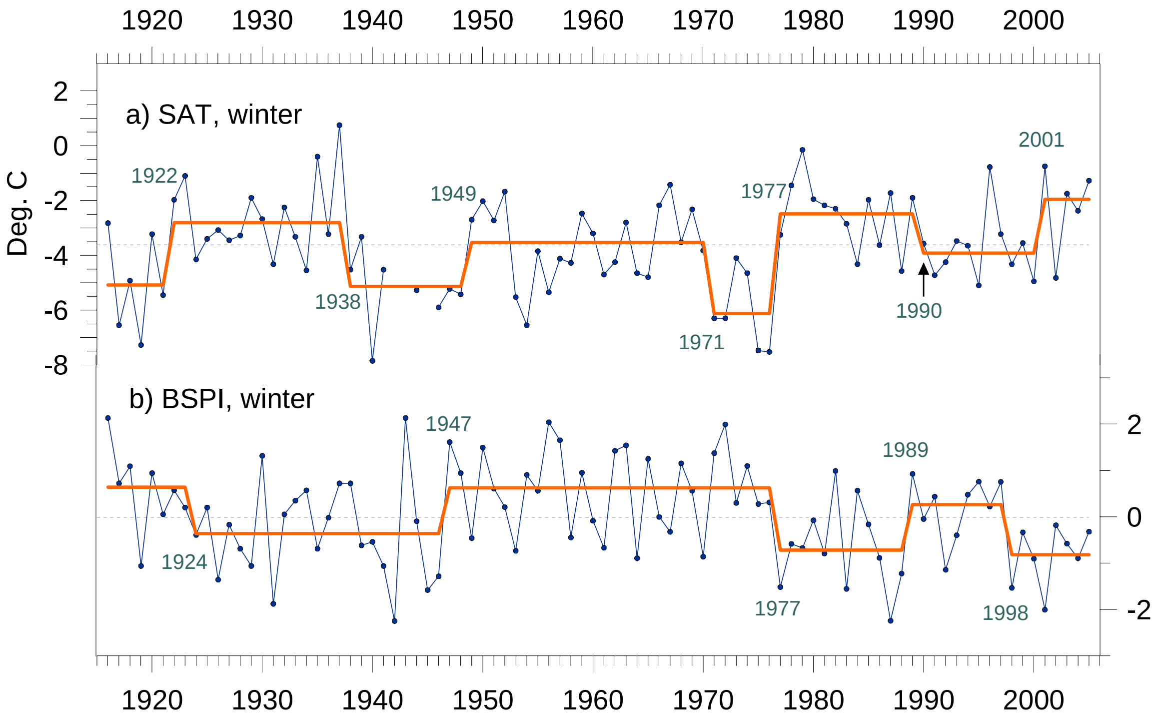

Figure 18. Mean winter (DJFM) a) surface air temperatures in St. Paul, Pribilof Islands and b) Bering Sea pressure index. The dashed line for the top graph indicates the mean SAT value of -3.62˚C for the base period, 1961-2000. Positive (negative) values of BSPI suggest anticyclonic (cyclonic) conditions in the Bering Sea. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the variables. Shift points were calculated using the sequential method (Rodionov 2004), with the cutoff length of 10 years, significance level of 0.2, and Huber weight parameter of 1. The latter reduces the effect of "outliers", if they exceed one standard deviation from the mean value of the corresponding regime.

To put this recent warmth in perspective, we calculated mean monthly SAT anomalies for the entire record since 1916 and smoothed them with 13-mo averages (Figure 19b). It is clear from this time series that the magnitude of the recent warmth is comparable with the major warm episodes in the 1930s and immediately after the regime shift in the late 1970s.

Figure 19b also shows three multidecadal regimes in SAT fluctuations: 1921-1939 (warm), 1940-1976 (cold), and 1977-2005 (warm). It is worth noting that the two previous regimes had a similar pattern, when SAT anomalies were strongest at the end of the regime, right before the system switched to a new one. In the current warm regime, the magnitude of SAT fluctuations has been steadily increasing since the mid-1980s, and the Bering Sea may become even warmer before it will switch to a new cold regime. If the regime concept is true, this switch may happen anytime soon, especially given the uncertain state of the North Pacific climate, suggesting that it may be in a transition phase (see the Pacific Climate overview section).

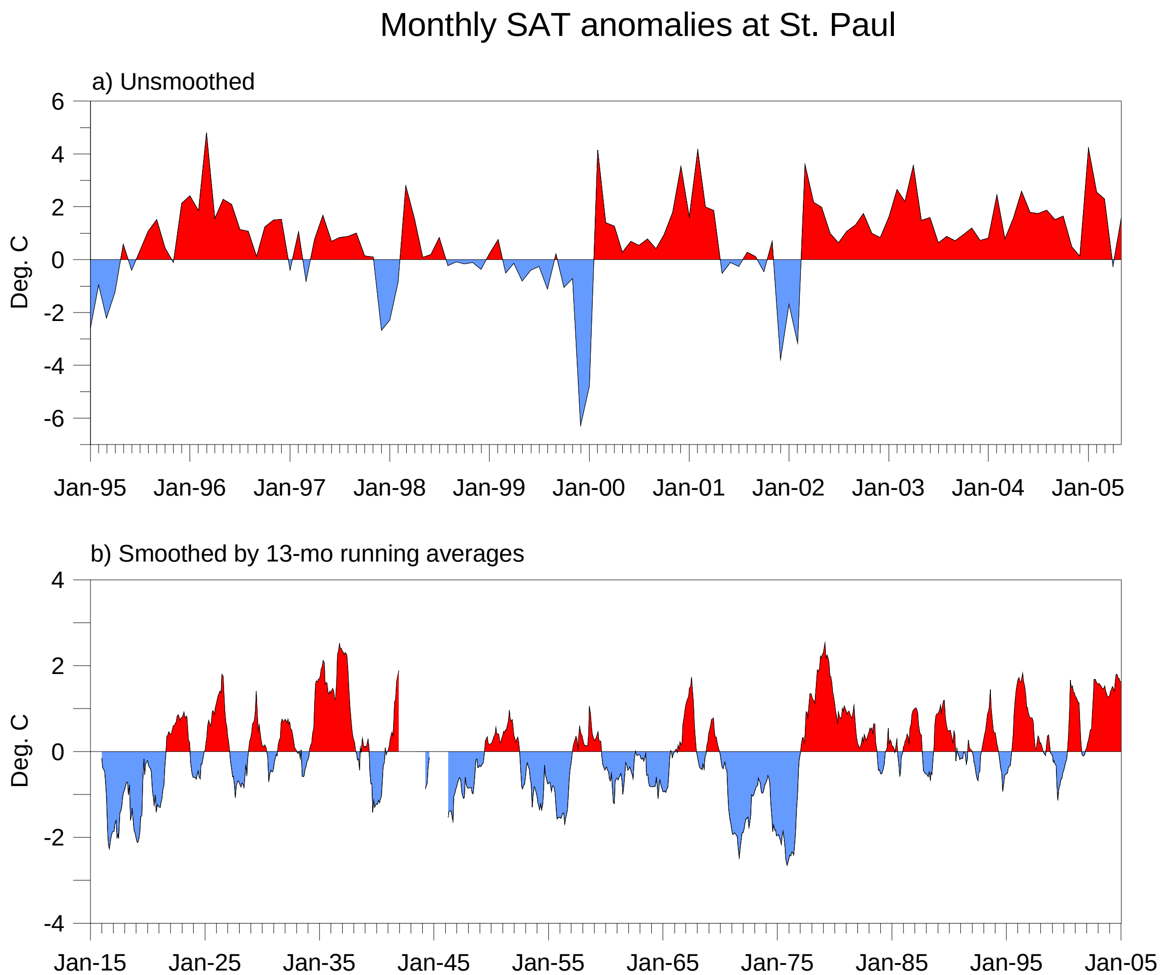

Figure 19. Mean monthly surface air temperatures anomalies in St. Paul, Pribilof Islands, a) unsmoothed, January 1995 through May 2005, and b) smoothed by 13-mo running averages and referred to the central month of the window, January 1916 through January 2005. The base period for calculating anomalies is 1961-2000.

An increase in year-to-year variability since the mid-1980s can also be seen in the Ice Cover Index (ICI, Figure 20a). In 2001, the ice cover index (ICI) plunged to a record low value, and then a new record was set in 2005.

As Figure 20b illustrates, there is a clear overall downward trend in the ice retreat index (IRI). The IRI represents the number of days with ice cover after March 15 in the 2˚ x 2˚ box (56-58°N, 163-165°W) that includes Mooring 2 (57˚N, 164˚W). Since the early 1970s, the index is declining at an average rate of almost 1 day per year, a trend significant at the 95% level. In the season of 2005, ice was practically absent in the box. A brief cold spell in April did bring about ice barely above the 10% threshold (Figure 21). This threshold is used to calculate the beginning and end of ice season (Figure 22). Based on this definition, the 2005 ice season lasted only 5 days. Similarly short ice seasons (less than 2 weeks) were observed in 2001 and 2003. In 2000 and 2002, in contrast, ice arrived to the vicinity of Mooring 2 very early, about one month prior to the average date for the beginning of ice season on January 14. Note, however, that starting with the 1996 ice season, if ice arrives early, it retreats early too (with the exception of 1999). This supports the shift in the Bering Sea toward earlier spring transition (Stabeno and Overland 2001).

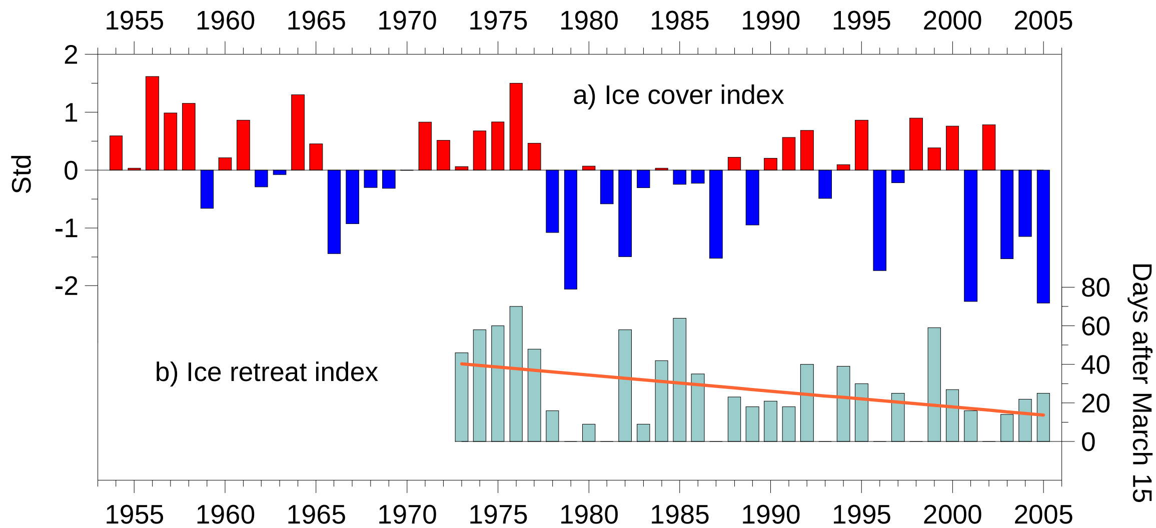

Figure 20. a) Ice cover index, 1954-2005, and b) ice retreat index and its linear trend (orange line), 1973-2005.

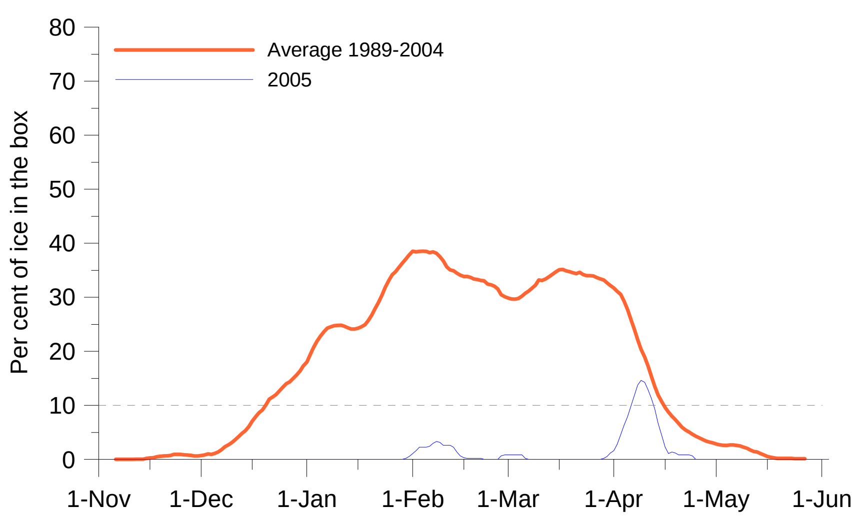

Figure 21. Percentage of ice cover in the 2˚ x 2˚ box (56-58°N, 163-165°W) during the winter of 2005.

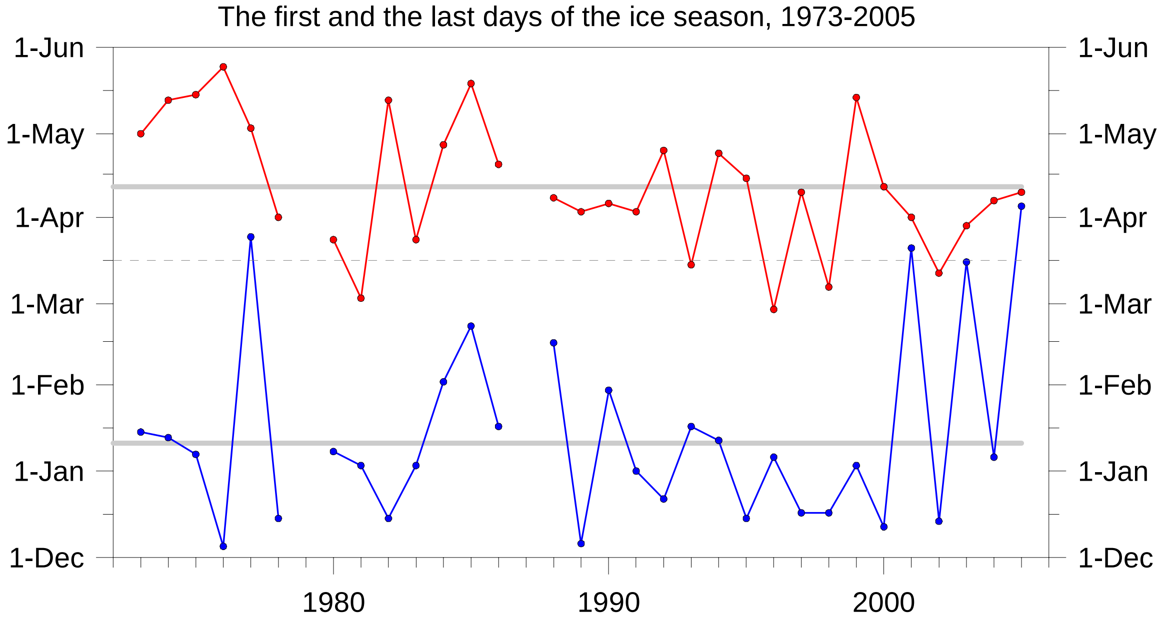

Figure 22. The first and last days of the ice season, 1973-2005. The gray solid horizontal lines are the mean dates for these two variables. The dashed line (March 15) is used as a threshold to calculate the ice retreat index. No ice was present in the box in 1979 and 1987.

The decrease in sea ice directly impacts water column temperature and salinity, and the timing of the spring bloom. These changes can be seen clearly in the data collected at two sites, Mooring 2 and Mooring 4 (Figure 23). The very cold temperatures (indicated by black) are accompanied by the *in situ* melting of ice. Generally, stratification develops during April. The water column exhibits a well-defined two-layer structure throughout the summer consisting of a 15-25 m wind mixed layer and 35-40 m tidally mixed bottom layer. When the bottom temperature is less than 2˚C, by definition it represents a “cold pool”. In earlier years (1995, 1996, 1997, and 1999) bottom temperatures were below the 2˚C threshold, but in more recent years the temperatures are much warmer, indicating the failure of the formation of the southern cold pool.

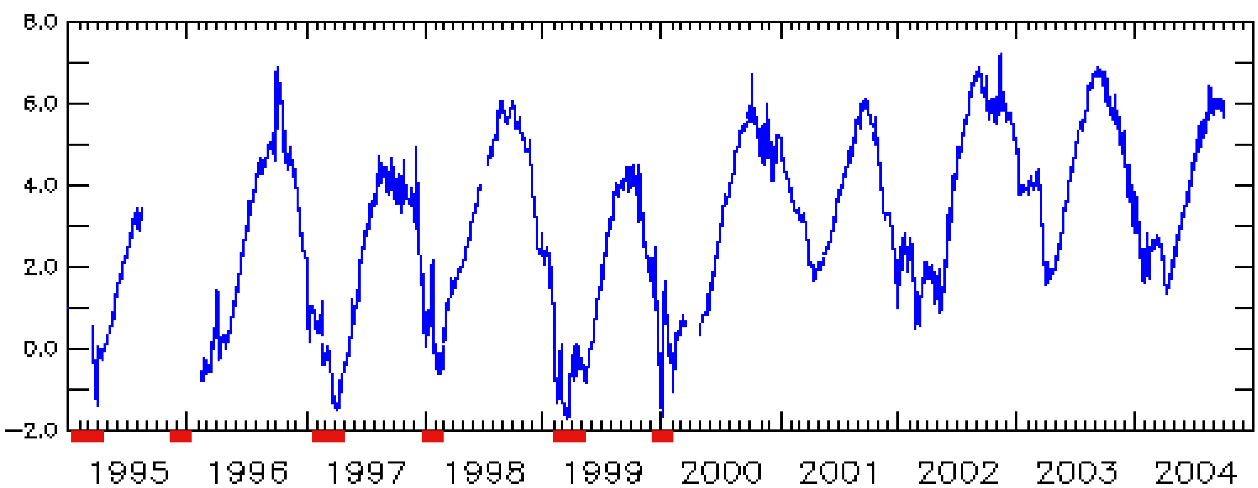

Figure 23. Depth integrated temperature at Mooring 2. The red lines at the bottom of the plot indicate when ice was present over the mooring.

The depth-averaged temperature at Mooring 2 (Figure 24) includes strong annual cycle, of course, but also a striking transition that occurred in 2000. During each winter from 1995 through 2000, ice was advected over the site cooling the water column. Beginning in 2001, ice (concentration greater than 10%) has not been over the mooring. This has been accompanied by a prominent warming of 3˚C in the winter and about 2˚C in the summer.

Sea surface temperature in May, when the southeastern Bering Sea is free of ice, appears to be a good predictor for summer bottom temperature. The correlation coefficient between May SSTs averaged over the southeastern Bering Sea (MaySST index) and mean bottom temperature for the same region is $r = 0.82$ ($P < 0.001$) for the period 1982-2003. Although May SST somewhat decreased in the past two years from its all-time maximum in 2003, it remains well above its long-term average value (Figure 25). Therefore, all indications are for a continuation of the warmth of the recent years through the summer of 2005.

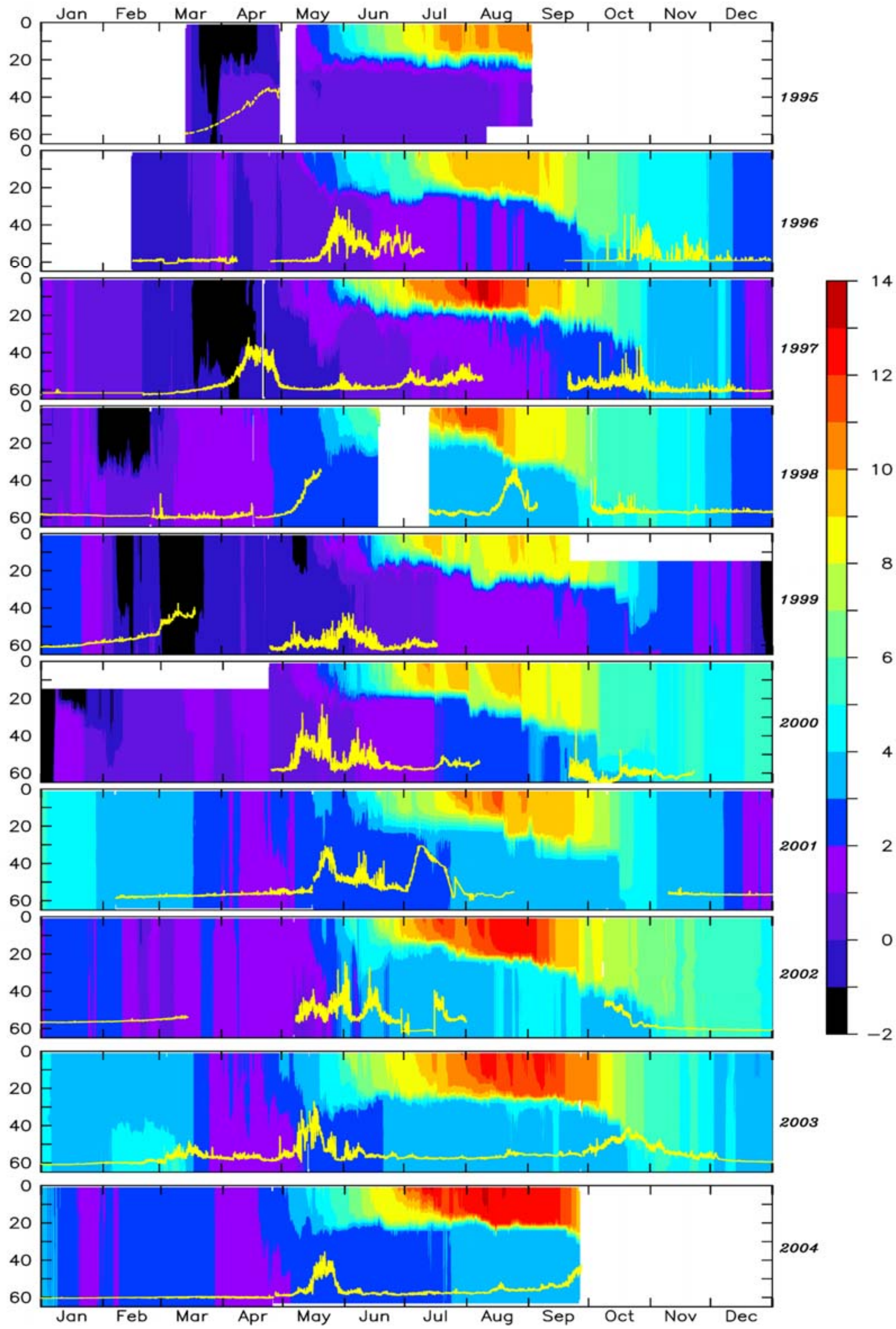

Figure 24. Contours of temperature measured at Mooring 2, 1995-2004. The coldest temperature (black) occurred when ice was over the mooring. The yellow line is fluorescence measured at ~11m. Note that early blooms are associated with the presence of ice.

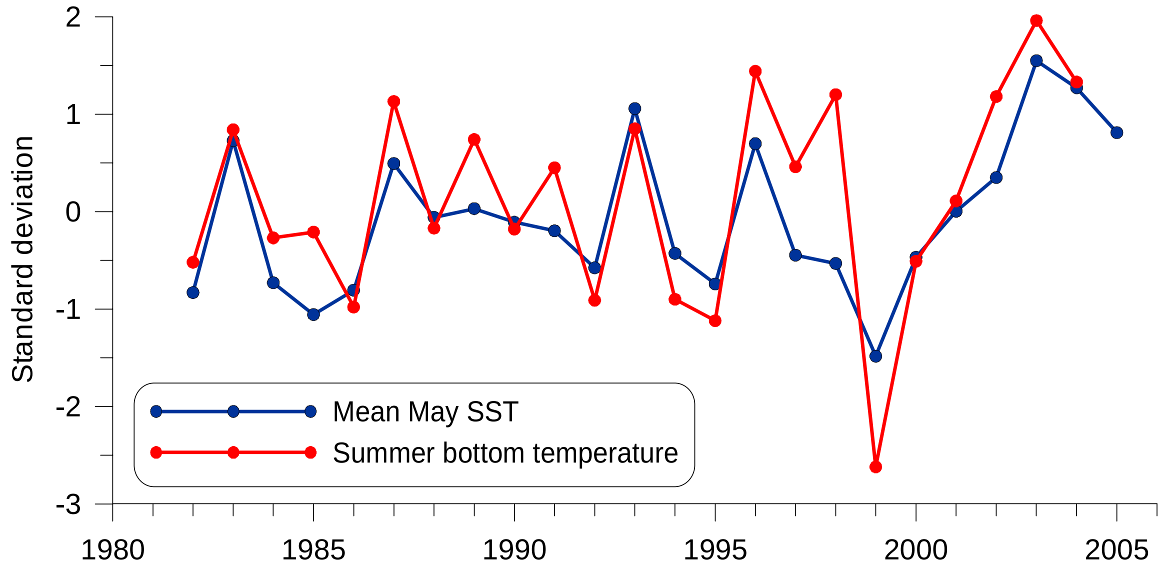

Figure 25. The MaySST index and mean summer bottom temperature in the southeastern Bering Sea, 1982-2005.